[Title of the Invention] PATTERN FORMING METHOD AND EXPOSURE APPARATUS FOR USE IN SUCH METHOD

[ABSTRACT]

[Summary]

[Constitution] A mask pattern (3) is imaged on a substrate (5) by using a reflective lens (7) and all or a part of an optical path of an exposure optical system including a space between the surface of the substrate (5) and the reflective lens (7) is filled with a liquid whose refractive index at an exposure wavelength is 1 or greater.

[Effect] It is possible to achieve an effect of improving resolution equivalent to reducing a wavelength easily and effectively so as to improve the resolution limit of optical lithography by the order of 30%, whereby a 0.15 μm or smaller pattern can be formed.

[Scope of Claims for Patent]

[Claim 1] A pattern forming method of forming a pattern on a substrate by irradiating a mask with light emitted from a light source via an illumination optical system to image the pattern on the mask onto the substrate using a projection optical system, wherein the projection optical system is composed of an optical system including a reflective lens and wherein all or a part of an optical path of the projection optical system including at least a space between the substrate and the projection optical system is filled with a medium whose refractive index relative to that of air at the wavelength of the light is 1 or greater.

[Claim 2] The pattern forming method according to claim 1, wherein the medium is a liquid.

[Claim 3] The pattern forming method according to claim 2, wherein the wavelength of the light is of 150 to 250 nm.

[Claim 4] A projection exposure apparatus for use in forming a pattern on a substrate by irradiating a mask with light emitted from a light source via an illumination optical system to image the pattern on the mask onto the substrate using a projection optical system, wherein the projection optical system is composed of an optical system including a reflective lens and wherein all or a part of an optical path of the projection optical system including a space between the substrate and the projection optical system is filled with a medium whose refractive index relative to that of air

at the wavelength of the light is 1 or greater.

[Claim 5] The projection exposure apparatus according to claim 4, wherein a transparent partition is interposed between the projection optical system and the substrate to divide the medium into optical system side and substrate side.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a pattern forming method for forming a fine pattern of various kinds of solid state components and a projection exposure apparatus for use in such method.

[0002]

[Background Related Art]

For the purpose of improving the degree of integration and the operating speed of LSI or other solid state components, miniaturization of a circuit pattern progresses. Currently, a reduction projection exposure method, which is superior in mass productivity and resolution performance, is widely used for their pattern formations.

[0003]

FIG. 2(b) schematically shows an optical system in the reduction projection exposure method. Light emitted from an effective light source 1 on a secondary light source plane is applied to a mask 3 via an illumination optical system 2 and the light diffracted by a pattern on the mask 3 forms an image onto a substrate 5 by means of a reduction projection

lens 4. The reduction projection lens used here is generally made of refractive lenses combined. Since the resolution limit of this method is in proportion to an exposure wavelength and in inverse proportion to the numerical aperture (NA) of a projection lens, the resolution limit has been improved by increasing the NA and decreasing the wavelength. Conventionally, a g-ray (wavelength: 436 nm) or i-ray (wavelength: 365 nm) of a high-pressure mercury lamp have been used as exposing light. The circuit, however, becomes smaller than the wavelength of light after the production of 64-megabit DRAM, and therefore this method has reached the physical limitation.

[0004]

On the other hand, there is known an (oil) immersion method as a method of effectively increasing NA of a microscope or any other optical system. This method effectively improves the resolution by decreasing the wavelength of light to 1/n by filling the space between the end of a lens and a sample with liquid (generally oil is used) having a higher refractive index n than air. The application of this method to optical lithography is described, for example, in the digest of the 53rd annual meeting of the Japan Society of Applied Physics, Vol. 2, pp.472 (1992).

[0005]

On the other hand, there has been studied a method using a reflective projection optical system in a step-and-

scan mode or the like in another form of the projection exposure apparatus for optical lithography. This optical system is recognized to be capable of achieving high NA of the order of max. 0.7 independently of the wavelength and therefore it is very promising as a future exposure apparatus. This system performs exposure in a relatively wide wavelength region, for example, of 245 to 253 nm of a xenon mercury lamp since chromatic aberration can be corrected though refractive optical elements are partially used. Accordingly, it does not require a narrow band of a precise laser wavelength spectrum nor a stable absolute wavelength, which will be required by a conventional excimer laser stepper using a completely refractive optical system, and can reduce the multiple interference effect and the standing wave effect. Moreover, the wide exposed area is a remarkable feature from a practical viewpoint.

[0006]

The step-and-scan optical system is discussed, for example, in "Resist Material Process Technology" (Technical Information Institute Co., Ltd., Tokyo, 1991, pp.12 to 14).

[0007]

[Problems to be Solved by the Invention]

The microscope or other refractive objective lens for use in the conventional immersion method is designed exclusively therefor on the premise that the space between the end of the lens and a sample is filled with liquid having a given refractive index. This condition is the same as in a

projection exposure lens. Therefore, the projection lens for liquid immersion need be particularly designed as a dedicated lens with a quite different design from that of the conventional lens. It is assumed here that a liquid filling space 6 (the shaded area in FIG. 2(b)) between the end of the conventional refractive lens other than a refractive lens for liquid immersion and a substrate (or a sample) is filled with a liquid having a refractive index n. In this instance, the wavelength decreases to 1/n effectively, but the angle of refraction at the end of the lens decreases according to Snell's law and therefore the optical path of the beam of light changes as indicated by a dashed line in FIG. 2(b), by which the effective NA decreases. Therefore, the resolution is not necessarily improved. Moreover, there has been a problem that it is extremely hard to satisfy both of the wide exposed area, which is required in a stepper lens, and the high NA specific to the immersion lens.

[0008]

On the other hand, it is preferable to decrease an exposure wavelength as much as possible in order to further improve the resolution of the optical lithography. In both of the exposure method using the conventional refractive optical system and the reflective projection exposure method, however, there has been a problem that an ArF excimer laser (wavelength: 193 nm) provides a practical limit to achieving a short wavelength due to the limitation in transmittance of optical materials.

[0009]

Therefore, an object of the present invention is to provide a pattern forming method capable of improving the resolution of a projection exposure method to the maximum while securing a wide exposed area by achieving an effect of increasing the resolution equivalent to reducing a wavelength easily and effectively, without significantly changing the configuration of the conventional exposure apparatus and the conventional optical system.

[0010]

[Means to Solve the Problem]

To achieve the above object according to an aspect of the present invention, there is provided a pattern forming method of forming a pattern on a substrate by irradiating a mask with light emitted from a light source via an illumination optical system to image the pattern on the mask onto the substrate using a projection optical system, wherein the projection optical system is composed of an optical system including a reflective lens, and wherein all or a part of an optical path of the projection optical system including at least a space between the substrate and the projection optical system is filled with a medium whose refractive index relative to that of air at the wavelength of the light is 1 or greater.

[0011]

[Operation of the Invention]

The following examines the situation of changing a

refractive index of a medium for filling all of an optical path of a reflective optical system shown in FIG. 2(a). FIG. 2(a) shows a system in which a reflective reduction projection lens 7 is used instead of a refractive reduction projection lens 4 shown in FIG. 2(b). In FIG. 2(a), a solid line and a dashed line indicate optical paths of beams of light observed when the refractive index of the medium is low and it is high, respectively. The optical path within the reflective optical system is determined only by the surface shape of the reflective lens according to the law of reflection, and it is independent of the refractive index of the medium. Therefore, a change in the refractive index of the medium does not change geometrical-optical characteristics of the optical system including NA. On the other hand, if a material of a refractive index n relative to vacuum is used as the medium, the wavelength effectively decreases to 1/n. As a result, it is possible to achieve the same effect as in the case where only the wavelength is reduced substantially. While the description has been made with reference to FIG. 2(a) on the assumption that the complete reflective optical system is used for simplification, it is also possible to partially use a refractive optical system.

[0012]

The medium preferably has as high refractive index as possible to the exposure wavelength and preferably has a refractive index of 1.2 or greater in order to obtain a

sufficient resolution effect. Moreover, preferably the medium is substantially transparent to the exposure wavelength and does not adversely affect optical elements and resist. More specifically, it is possible to use, for example, water or alcohol, organic solvent including straight-chain hydrocarbon, silicone resin, or a liquid obtained by dissolving inorganic compound or organic compound in these, or any of various liquids conventionally used for an immersion microscope or in an immersion refractive index measurement method.

[0013]

If the refractive index changes due to fluctuation in temperature, density, or the like of the medium in the optical system, it could lead to an adverse effect on an imaging characteristic of the optical system. Therefore, it is preferable to control the temperature and the like carefully. Particularly, since a substrate is scanned relative to the optical system in a scanning optical system, it is preferable to see to it that the imaging characteristic is not changed by the flow of the medium.

[0014]

[Embodiment]

(First embodiment)

Referring to FIG. 1, there is shown a reflective projection exposure apparatus according to one embodiment of the present invention. A mask 3 is irradiated with a laser beam 12 emitted from a KrF excimer laser 11 via a beam

forming optical system 13 and an illumination optical system 2. A substrate 5 is exposed to light, which has passed through the mask, via a reflective reduction projection lens 7. The reflective reduction projection lens, which is a Schwarzschild-type optical system of 0.3 NA, forms an image of the mask 3 onto the substrate 5. Note here that the optical system in the diagram is only schematic and it does not faithfully represent the configuration of a practical optical system. In this condition, the entire optical system from the emission side of the illumination optical system via the mask to the substrate is placed inside a liquid container 14 and the liquid container 14 is filled with water so as to fill the optical path with water.

[0015]

Subsequently, patterns of various sizes are transferred to a positive resist film (PMMA, 1 μm of film thickness) applied to a Si substrate by using the projection exposure apparatus. As a result, a 0.35 μm L/S pattern has been formed successfully. For comparison, the exposure is performed in the air after draining the water from the optical system. Consequently, the resolution limit has been deteriorated to 0.5 μm.

[0016]

The wavelength of the exposure apparatus, the type of the light source, the feature and NA of the projection lens, the type of medium, a resist process to be used, a mask pattern size, and the like are not limited to those described

in this embodiment. For example, a high-pressure mercury lamp or xenon mercury lamp can be used instead of the excimer laser. Moreover, perfluoroalkylpolyether or the like can be used instead of water for the liquid solution. This liquid is transparent to the exposure wavelength and did not affect the photosensitive characteristics of the resist at all. In addition, an appropriate novolac positive resist or chemical amplification resist can be used instead of PMMA as a resist.

[0017]

(Second embodiment)

Referring to FIG. 3, there is shown a reflective projection exposure apparatus according to a second embodiment of the present invention. A mask 3 is irradiated with a laser beam emitted from an ArF excimer laser (not shown) via a beam-shape forming optical system and an illumination optical system (not shown). A substrate 5 is exposed to light, which has passed through the mask, via a scanning reflective optical system 21. The scanning reflective optical system, which is a step-and-scan optical system of 0.7 NA, forms an image of the mask 3 onto the substrate 5. Note here that the optical system in the diagram is only schematic and it does not faithfully represent the configuration of a practical optical system. In this condition, a shaded area 22 within the optical path of the projection optical system in the diagram indicates a space filled with water.

[0018]

Subsequently, patterns of various sizes are transferred to a positive resist film (PMMA, 1 μm of film thickness) applied to a Si substrate by using the projection exposure apparatus. As a result, a 0.11 μm L/S pattern has been formed successfully. For comparison, the exposure is performed in an air medium after draining the water from the optical system. Consequently, the resolution limit has deteriorated to 0.15 μm and thus the effect of the present invention has been confirmed.

[0019]

(Third embodiment)

In the projection exposure apparatus of the second embodiment, the medium is divided into optical system side and substrate side by a parallel plate 31 of quartz as shown in FIG. 4. This prevents the flow of the liquid medium from reaching the optical system side, which will occur when the substrate is scanned or step-fed relative to the optical system. Therefore, the effect of the fluctuation in the refractive index is limited, whereby the pattern size accuracy is improved. Note here that a spherical aberration caused by opening a quartz window is previously corrected.

[0020]

(Fourth embodiment)

Quartz parallel plates 32 and 33 are interposed between the optical system and the substrate as shown in FIG. 5 in the projection exposure apparatus of the second embodiment to divide the liquid container into an optical

system side liquid container 34 and a substrate side liquid container 35. Moreover, the scanning or step-feed of the substrate 5 relative to the optical system is performed for each substrate side liquid container 35. This suppresses the flow of the liquid in the vicinity of the substrate and therefore reduces effects of the fluctuation in refractive index or the like, which further improves the pattern size accuracy.

[0021]

If the configuration of this embodiment is applied to the first embodiment, the same mechanism can be placed also on the mask side.

[0022]

[Effect of the Invention]

According to the present invention, when a pattern is transferred to a substrate by imaging a mask pattern onto the substrate by using a projection optical system, the projection optical system is composed of an optical system including a reflective lens and all or a part of an optical path of the projection optical system including a space between the surface of the substrate and the projection optical system is filled with a medium whose refractive index relative to that of air at the wavelength of light is 1 or greater. This enables an improvement of resolution equivalent to reducing a wavelength easily and effectively, without significantly changing the configuration of the conventional exposure apparatus and the conventional optical

system. This improves the resolution limit of the optical lithography by the order of 30%, by which it is possible to form a 0.15 μm or smaller pattern.

[Brief Description of the Drawings]

[Fig. 1]

It is an explanatory diagram of the principle of the present invention.

[Fig. 2]

It is an explanatory diagram of an exposure apparatus according to one embodiment of the present invention.

[Fig. 3]

It is an explanatory diagram of an exposure apparatus according to a second embodiment of the present invention.

[Fig. 4]

It is an explanatory diagram of an exposure apparatus according to a third embodiment of the present invention.

[Fig. 5]

It is an explanatory diagram of an exposure apparatus according to a fourth embodiment of the present invention.

[Explanation of the Reference Numerals]

2 Illumination optical system

3 Mask

5 Substrate

7 Reflective reduction projection lens

11 Excimer laser

12 Laser beam

13 Beam-shape forming optical system

14 Liquid container